

STATUS OF RADIO ICE CERENKOV EXPERIMENT (RICE)

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ABSTRACT

The Radio Ice Cerenkov Experiment (RICE) is designed to detect ultrahigh energy (≥ 100 TeV) neutrinos from astrophysical sources. RICE will consist of an array of compact radio (100 to 1000 MHz) receivers buried in ice at the South Pole. The objective is an array of greater than one cubic kilometer effective volume, complementary to TeV optical neutrino telescopes. The effective volume using the radio technique increases faster with energy than the optical technique, making the method more efficient at ultrahigh energies. During the 1995-96 and 1996-97 austral summers, several receivers and transmitters were deployed in bore holes drilled for the AMANDA project, at depths of 141 to 260 m. This was the first *in situ* test of radio receivers in deep ice for neutrino astronomy.

INTRODUCTION

The detection of ultrahigh energy neutrinos represents a unique opportunity in astrophysics. Photons of such energy are attenuated on the cosmic microwave background, while protons are deflected in intergalactic magnetic fields and do not point back to their source. The potential to observe objects not seen by any other method has stimulated much recent theoretical and experimental work. Several production sites of high energy neutrinos have been theorized, including massive black holes at the center of the Milky Way or Active Galactic Nuclei (AGN), superconducting cosmic strings, the sources of the highest energy cosmic rays, gamma ray bursts, young supernova remnants, and X-ray binary systems. Fluxes from these potential sources are small enough that detectors with active volumes on the order of 1 km^3 are needed in order to observe them (Gaisser et al., 1994). Several high energy neutrino projects, including AMANDA (see HE 4.1.1), NESTOR (Resvanis, 1993), and Baikal (Bezrukov, 1995), are now underway. These projects all use photomultiplier tubes in deep water or ice to observe visible and UV Cerenkov light emitted by muons created in charged current interactions by ν_μ , and all are optimized for detection of $\sim \text{TeV}$ neutrinos.

RICE DESCRIPTION

The Radio Ice Cerenkov Experiment (RICE) is a new experimental effort to detect ν_e at $\sim \text{PeV}$ energies through the principle of “radio coherence”. An UHE ν_e that undergoes a charged current interaction in the ice will transfer most of its energy to the resulting electron and subsequent electromagnetic shower. A charge imbalance will develop as positrons are annihilated and atomic electrons

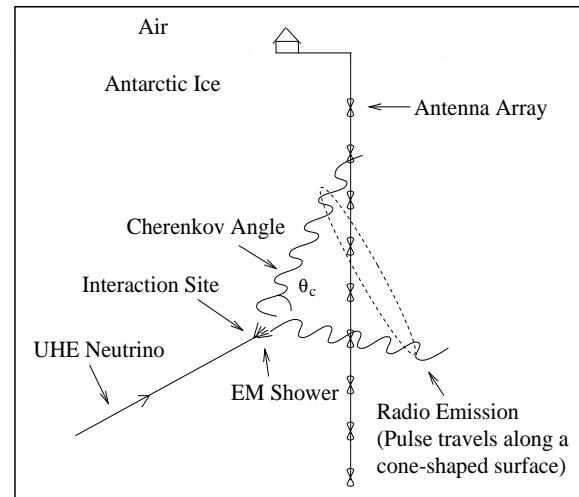


Fig. 1: The RICE concept. An UHE electron neutrino initiates an electromagnetic shower in Antarctic ice. The resulting radio pulse is detected by a buried array of receivers.

are scattered into the shower. Monte Carlo calculations find that the net charge is about 20 percent of the total number of electrons (Halzen et al, 1991). This moving blob of net negative charge will produce coherent Cerenkov radiation at wavelengths larger than its own spatial extent (~ 10 cm), corresponding to radio frequencies ($\nu \leq 1$ GHz). This radiation is observed by an array of radio receivers (Rx) buried in the ice cap or on the surface (see Figure 1). The expected signal shape is of very short duration, and depends upon the antenna used and the details of signal transmission (see Figure 2). The location, direction, and size of the shower are determined from the timing and signal size in several Rx. Since the charge excess scales as E_ν , the coherent power radiated scales as E_ν^2 , and the volume of ice sensed by a single detector grows as E_ν^3 , up to volumes where signal attenuation becomes important (Frichter et al., 1996, Provorov and Zheleznykh, 1995). This growth with energy is greater than that in the optical regime, making the radio method more efficient at PeV energies but much less efficient at TeV energies (see Figure 3). Several features of Antarctic ice make it an attractive target medium. It is an abundant, cheap, high purity material, and cold ice has extremely long attenuation lengths at radio frequencies, of order 1 km at 100 MHz to 1 GHz. Also, the AMANDA project has successfully installed instruments in several deep bore holes at the South Pole, demonstrating that deployment in deep ice is feasible (see HE 4.1.1). Radio coherence was first described by Askar'yan (1962), and previous tests in ice have been undertaken by Boldyrev et al. (1987). However, that effort involved only antennas on the snow surface. RICE is the first project using radio receivers placed in the ice.

PILOT EXPERIMENT

RICE tests have been made at the South Pole during the 1995-96 and 1996-97 seasons. Rx and transmitters (Tx) were deployed on the surface and in AMANDA bore holes. All antennas deployed thus far have been cylindrical dipoles, oriented vertically. This design has a relatively narrow bandwidth, but it is easiest to deploy on an AMANDA cable in a narrow bore hole. Several competing factors are involved in determining the optimum center frequency for the antennas. The Cerenkov emission increases with frequency up to a cutoff at ~ 1 GHz. However, the ice transparency and the thickness of the radio Cerenkov cone are greater at lower frequencies, increasing the likelihood of hits in multiple Rx. In addition, cable losses are much greater at high frequencies. A Monte Carlo program developed by the RICE collaboration indicates that the optimum frequency for an array of dipole antennas may be in the range of 200 to 300 MHz.

In 1995-96, one Tx was placed on the snow surface and two Rx were deployed in the ice. Each Rx consisted of a dipole antenna and a pair of 36dB HEMT amplifiers in series enclosed in a cylindrical pressure vessel. The two amplifiers in close proximity created an oscillation at ~ 100 MHz, which could not be eliminated because the amplifiers were inaccessible. During 1996-97, four more Rx and three Tx were deployed in the ice. The Rx design was improved by placing only one amplifier in each pressure vessel, with the second stage on the surface, which eliminated the oscillations. The buried Tx each consist of a dipole antenna connected by coaxial cable to an HP8133A signal generator on the surface. The in-ice amplifier stage failed on one of the four Rx, and one of the three Tx produces

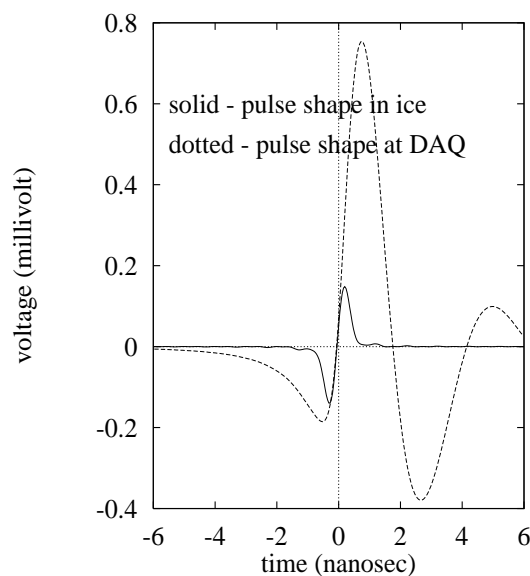


Fig. 2: Modeled pulse shapes for the 96-97 RICE array. The solid curve is the expected pulse in the ice and the dotted curve is the pulse at the input to the data acquisition. The limited bandwidths of the antenna and cable broaden the pulse.

no observable signal. The characteristics of the current RICE array are summarized in Table 1.

Table 1: RICE Module Summary

Type	(X,Y,Z) (m)	Center Freq. (MHz)	14dB points (MHz)	Date Deployed
Tx 0	Surface	variable	N/A	1/96
Rx A	(-24,-27,-260)	127	115/138	1/96
Rx B	(31,-6,-150)	134	124/142	1/96
Tx 1	(64,4,-201)	280	267/291	12/96
Rx 2	(-56,34,-152)	265	246/285	1/97
Rx 3	(-56,34,-213)	264	247/285	1/97
Rx 6	(48,34,-166)	253	237/267	1/97
Tx 9	(25,48,-141)	260	242/287	1/97

Cable losses set the maximum depth and antenna frequency. The signal cables used were RG-8 on Rx A, RG-59 on Rx B, and LMR-500 on all others. The data acquisition system consists of an HP-54542A digital oscilloscope read out by a Macintosh computer running LabView software. The oscilloscope can operate in two trigger modes: noise mode, where samples of data are taken at periodic intervals, and glitch mode, where data samples are recorded when a particular channel exceeds a given threshold for less than a specified time.

There are several objectives of the current RICE array. First, as the first deployment of radio receivers in deep ice, it is an engineering test. Second, we must measure man-made background noise that could produce false triggers. While the South Pole is relatively free of radio noise, there are still a number of background sources due to the manned research base. Next, we must measure the noise temperature of the ice. This will ultimately determine the detection threshold of the array. Also, we must demonstrate the ability to reconstruct event positions. To determine the energy of a neutrino event, the shower location must be found from the timing information in several Rx. Otherwise large showers outside the array cannot be distinguished from smaller showers inside. This can be tested by sending narrow pulses to buried Tx and reconstructing their known locations. Finally, we must determine how the close proximity of AMANDA main cables, which each consist of 18 twisted quad electrical cables, distorts the beam pattern of the RICE antennas.

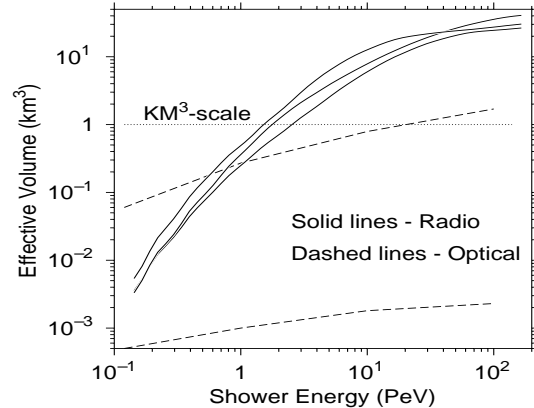


Fig. 3: Comparison of effective volume per detector module. The radio lines are for different zenith angles. The upper and lower optical lines are for clear and bubbly ice, respectively (Price, 1996)

RESULTS AND CONCLUSIONS

Continuous wave signals at frequencies of 200 to 300 MHz sent to working Tx are observed by all Rx. Spectra seen by Rx 6 with Tx 1 on and off are shown in Figure 4. The spike at 250 MHz is clear in the ON sample and absent in the OFF sample. Numerous other spikes are seen in both samples, indicating man-made background noise. In future deployments, high amplitude signals from local noise must be reduced at the front end of the electronics by a band-pass filter. The relative signal sizes observed in Rx 2, 3, and 6 are consistent with cable losses, amplifiers, distances, and a $\cos^2\theta$ beam pattern. However, preliminary results indicate that the frequency response of the antennas is distorted by the presence of AMANDA cables in the same bore holes. Measurements of background noise temperature and timing resolution/position reconstruction are in progress.

Our experience indicates several areas for improvement. Ten dipole antennas (5 Rx and 5 Tx) are under construction for the 1997-98 season. If possible, several will be deployed in bore holes separate from AMANDA. PMT modules using optical fiber for signal transmission have been developed and deployed at depths of ≥ 1500 m by AMANDA (Karle et al, 1997). Work is underway to modify this technology for RICE, which will allow us to deploy at much greater depth and eliminate cross talk and noise pickup in the signal cables. Work is also underway to develop wider bandwidth and more sensitive antennas.

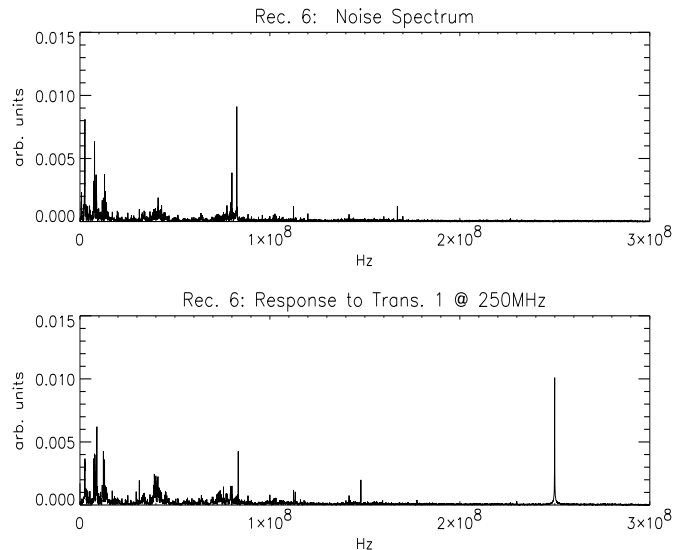


Fig. 4: FFT of signal observed in Rx 6 with Tx 1 off (top) and on (bottom).

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REFERENCES

- Askar'yan, G.A., *Sov. Phys. JETP* **14**, 441 (1962).
- Boldyrev et al., *Proc. 20th Int. Cosmic Ray Conf.*, **6**, 472 (1987).
- Bezrukov, L.B. et al., presented at *2nd Workshop on the Dark Side of the Universe: Experimental Efforts and Theoretical Framework*, Rome, Italy (1995).
- Frichter, G.M., Ralston, J.P., McKay, D.W., *Phys. Rev.* **D53**, 1684 (1996).
- Halzen, F., Zas, E., Stanev, T., *Phys. Lett.* **B257**, 432 (1991).
- Gaisser, T.K., Halzen, F., Stanev, T., "Particle Astrophysics with High Energy Neutrinos", **hep-ph/9410384** (1996).
- Karle, A., et al., *Proc. 25th Int. Cosmic Ray Conf.* (Durban, 1997).
- Price, P.B., *Astropart. Phys.*, **5**, 43-52, (1996).
- Prozorov, A.L., Zheleznykh, I., *Astropart. Phys.* **4**, 55 (1995).
- Resvanis, L.K., Ed., *Proc. of 3rd NESTOR Workshop*, Athens, Greece, Univ. Press (1993).